

High-Resolution Simulation Test Bed for the Urban and Complex Terrain Environment

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LONG-TERM GOALS

A large fraction of the world's population lives in urban areas, many of them coastal. The U.S. military frequently operates in these urban coastal areas. Current operational forecasting models do not sufficiently account for urban effects. This research is motivated by the need for improved mesoscale prediction at high horizontal resolutions (< 2 km) over urban regions. The focus of the effort is on urban regions in the coastal zone and urban regions in areas of complex topography. The earth's surface is characterized by inhomogeneities due to variations in vegetation types, soil types and moisture, canopy layers, and topography, as well as urban effects. These inhomogeneities all act together but often on different spatial and temporal scales to produce gradients in surface fluxes of momentum, heat, and moisture that drive three-dimensional circulations and significantly alter the low-level mesoscale thermodynamic and dynamic structure. The well-recognized urban heat island phenomenon is one of major impacts resulted from these inhomogeneities. Land-surface processes also critically impact aerosols and boundary layer visibility because nearly all aerosol source and sink processes occur on small scales, and most aerosols originate at the surface and pass through the surface and boundary layers at least once during their lifetime. Furthermore, surface aerosol processes such as mobilization, deposition, and re-suspension are highly dependent on surface roughness, vegetation, and soil moisture.

Doppler radar data can, in principle, provide the entire dynamical and hydrological structure of the three-dimensional atmosphere with high spatial resolution (up to 250 meters) and nearly continuous update rate (every 6 minutes). It can then be used, together with other observations, to initialize and validate high-resolution mesoscale models over urban regions. The incorporation of an urban canopy parameterization and Doppler radar data to account for urban effects in the Coupled

Ocean/Atmosphere Mesoscale Prediction System (COAMPSTM)¹ will directly impact mesoscale forecasts of atmospheric state parameters and aerosols through more accurate prediction of surface fluxes, boundary layer turbulence and mixing, moisture transport, and radiative effects.

OBJECTIVES

The objective of the proposed work is to incorporate an urban canopy parameterization and radar retrievals to account for urban effects in COAMPSTM and to validate high-resolution (~ 1 km) simulations over urban regions with newly available in-situ observational data. One such

¹ COAMPS is a trademark of the Naval Research Laboratory

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observational network used in this project is the Washington, D.C. metro area network, DCNet, (http://www.arl.noaa.gov/pubs/news/dcnet_072003.html). Horizontal inhomogeneity in land surface characteristics can produce variations in fluxes of momentum, heat, and moisture that drive three-dimensional circulations and significantly alter low-level thermodynamic and dynamic mesoscale structures. Inhomogeneities include horizontal variations in topography and surface characteristics, such as ground wetness, surface roughness, and the urban landscape. These high-resolution simulations can be used as mechanism for testing advanced land-surface and urban parameterizations as well as providing data for subsequent consequence analyses.

APPROACH

The task will focus on the inclusion of urban environment parameterization methods and specification of land-surface types using a soil model. A mesoscale data assimilation system using both a multivariate optimum interpolation (MVOI) and the 3.5-dimensional variational analysis (3.5DVAR) will also be developed for assimilating the retrieved information from Doppler radar data into COAMPSTM. Long-term (~ two week) data assimilation experiments with horizontal resolution on the finest nest of ~ 1 km or less will be conducted to examine the sensitivity of mesoscale structures to varied surface forcing. Validation of numerical simulations will be performed against available high-resolution mesonet data (e.g., DCNet) in urban environments. Experiments will examine the effect of the urban environment parameterization methods and the land-surface types using a soil model on the simulated urban mesoscale structure. Variations in the surface properties on the mesoscale have been shown to have strong effects on mesoscale dynamic and thermodynamic structure. However, the sensitivity of numerical forecasts at horizontal resolutions on the order of kilometers to the representation of the land surface and the urban environment is not known. For high horizontal resolutions, it is hypothesized that information from the finest grid mesh may have an important influence on the mesoscale environment. For example, it is well known that urban heat island effects can influence downstream winds and precipitation. Data from these simulations will also be provided for driving relevant transport and dispersion models.

WORK COMPLETED

In fiscal year 2003, research has been focused in two areas: radar data assimilation and urban effects modeling. Radar data assimilation research has been focused on studying the impact of assimilated wind and cloud information from Doppler radar data on mesoscale analysis and prediction. For this purpose, several efforts have been made. First, the 3.5DVAR radar wind analysis system has been enhanced to use radar data from multiple radars instead of from a single radar. While the main purpose of this improvement is to increase the radar data coverage, the accuracy of retrieved information in areas covered by multiple radars is also improved due to the increase in data resolution and the number of wind components observed by different radars that cover the area. Improvements to the system also include the use of the multivariate background error covariance and the recursive B-spline filter recently developed by Xu and Gong (2003) in the 3.5DVAR radar wind analysis system to improve the wind analysis from radar observations. Second, the data assimilation system has been tested extensively with cases of various synoptic conditions, including large-scale frontal systems and isolated thunderstorms. Two research areas have been studied with considerable effort: i) the value of observed radar radial winds added to three-dimensional wind analysis, and ii) the impact of the retrieved information on model forecast. In addition, COAMPSTM 3.0 and 3.5DVAR have been

modified to establish a direct link between these two systems for the development of real-time capability of radar data assimilation at NRL.

Research on urban effects modeling has focused on the implementation and validation of the urban canopy parameterization (UCP) and a land-surface model (LSM) into COAMPSTM. The UCP, originally developed by Brown and Williams (1998), modified by Chin et al. (2000), takes into consideration the momentum loss, turbulent production, radiation absorption and modified surface radiation budget resulting from the urban building canopy (Fig. 1). A modified land use/land cover (LULC) specification of urban characterization, ranging from industrial to high or low intensity residential, has also been included to improve the prediction in the urban canopy (Fig. 2). A 24-h COAMPSTM simulation was performed to test the sensitivity of these added model capabilities.

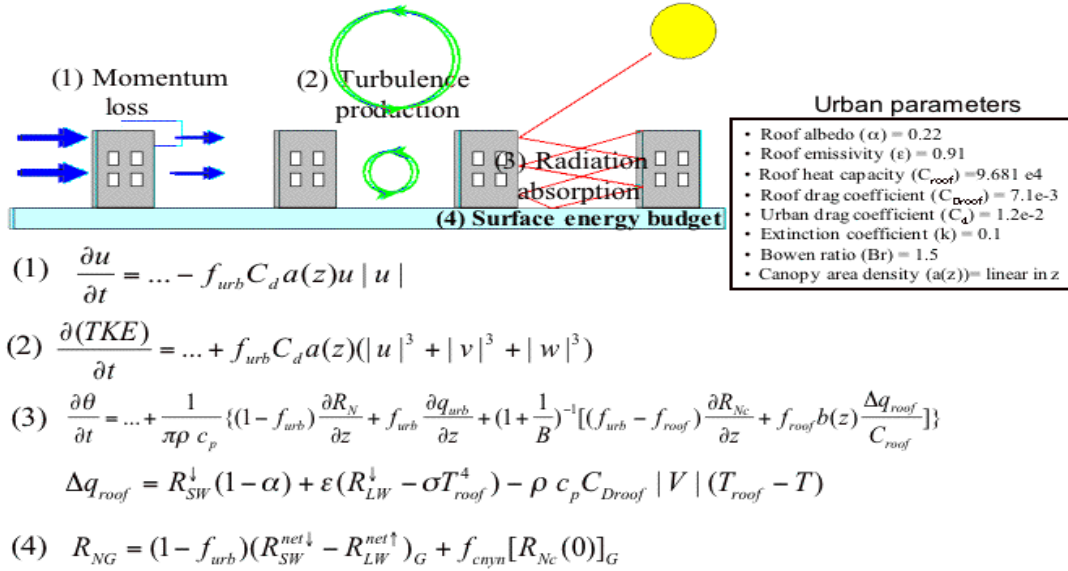


Figure 1. Urban Canopy Parameterization incorporated into COAMPS

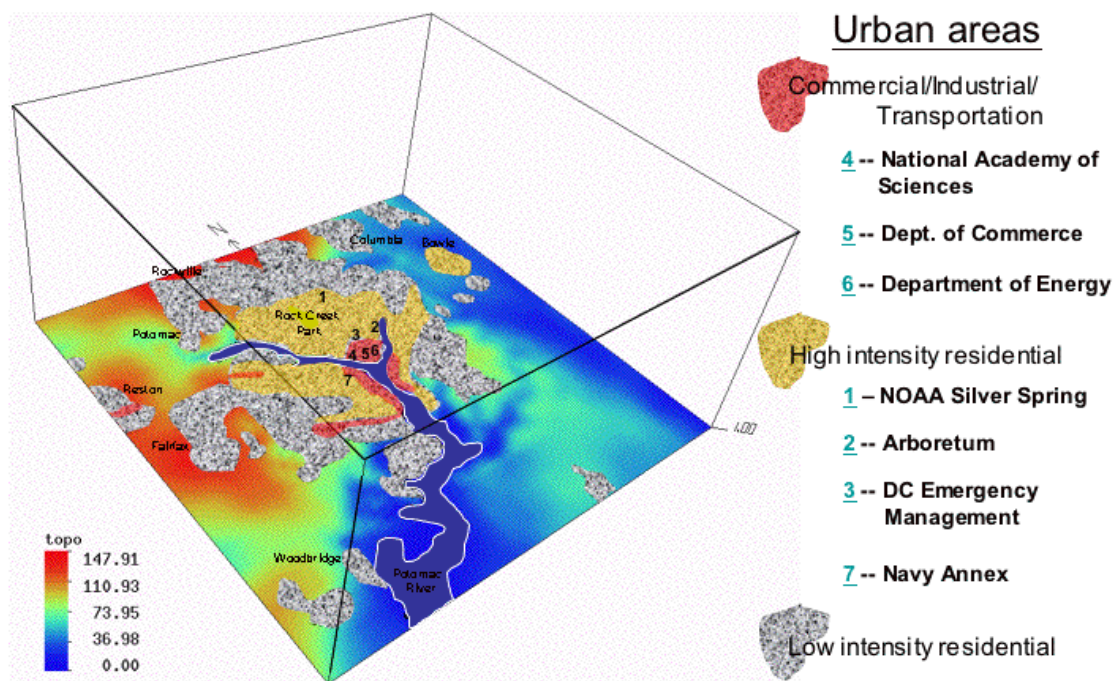


Figure 2. Washington, DC Metro Area Nest 4 1-km resolution (61 x 61 km)

RESULTS

Results from the 24-h simulation indicate the dominant effects of the UCP for this case study are: i) an increase in low-level temperatures at night (that agree better with observations) (Fig. 3a) and subsequently a decrease in low-level stability at night; ii) an increase in turbulent mixing most prominent at night; iii) a reduction in low-level wind speeds (that agree better with observations) (Fig. 3b) for both day and night. Passive tracers were also released both within and above the urban canopy. At 2-m (within the urban canopy), the UCP resulted in reduced 2-m dosage and smaller footprints of high 2-m dosage due to increased low-level mixing of tracers and decreased wind speed. At 70-m (above the building canopy), the UCP resulted in larger 2-m dosage and a larger footprint due to downward mixing in the less-stable elevated layer at night. These results emphasize the critical importance of an UCP in accurately predicting urban-level winds and stability, which impact the subsequent transport of any materials released either within or above the urban canopy.

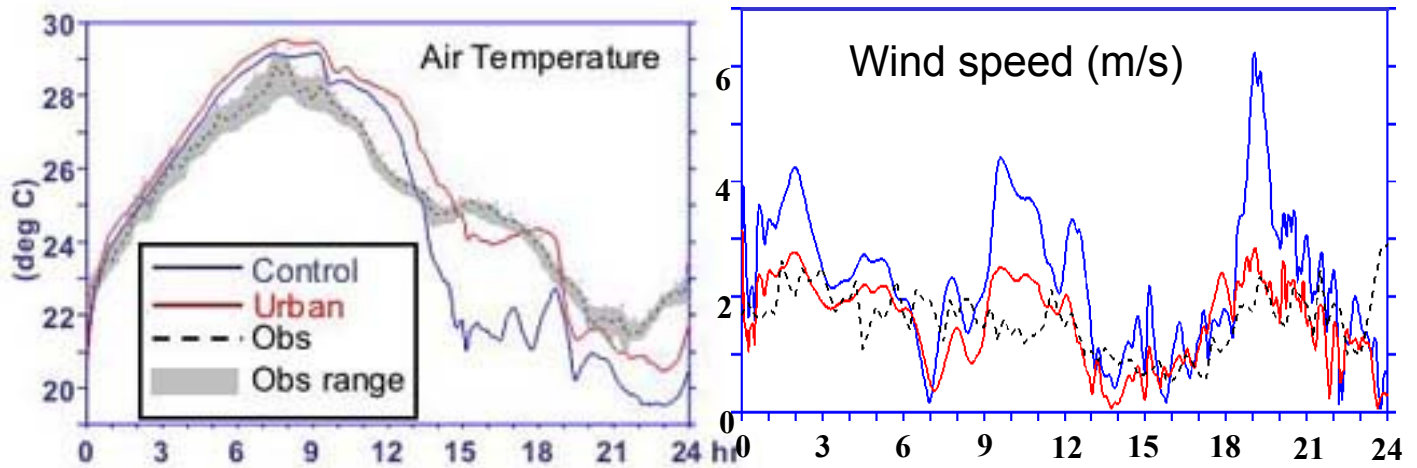


Figure 3. COAMPSTM 24-h forecast from 12 UTC 13 July to 12 UTC 14 July 2003 with the UCP (red line) and without the UCP (blue line) and observations (black dashed line) for (a) air temperature (C) at observation height (31 m) on top of the National Academy of Sciences Building, and (b) wind speed (m/s) at observation height on top of the Department of Commerce Building.

Several research efforts during the last year have also been made to test the data assimilation system with real Doppler radar data and to investigate the value of radar observed radial winds added to the three-dimensional wind analysis. Several case studies in Washington DC area have been conducted for this purpose. One example is the squall line case from 9–10 May 2003 in Washington DC, Virginia and North Carolina. In this study, radar radial velocities were collected during the storm period from three radars at Norfolk, VA, Raleigh and Morehead City, NC, respectively. COAMPSTM was run at 5 km resolution to provide first guess fields for the wind retrieval, with the 3.5DVAR system used to retrieve the three-dimensional winds. Figure 4 shows an example inside the storm system at 00 UTC 10 May 2003 of the vertical cross-section of wind increments (wind analyses minus first guess fields), emphasizing the impact of observed radar radial velocity on wind analyses. Areas of increased upward motion are observed inside the storm. It was also found that the largest changes in the wind analysis due to the radar data assimilation occurred above the 1 km level. This is believed to be caused by the lack of radar observations near the surface. Regardless, there is a remarkable impact of the observed radar radial velocity on lower level convergence noted in almost all the COAMPSTM case studies. Another interesting case was the frontal system on 29 October 2002 in the same region. In this case, a strong wind shear was observed by the Norfolk, VA radar. Below 1 km, winds were onshore (easterly), while above 2 km, strong westerly and southwesterly winds dominated. The retrieved horizontal winds at 0.7 km and 2.3 km, respectively, from the Norfolk radar (Figure not shown) clearly demonstrate the value of radar observations on the wind analysis.

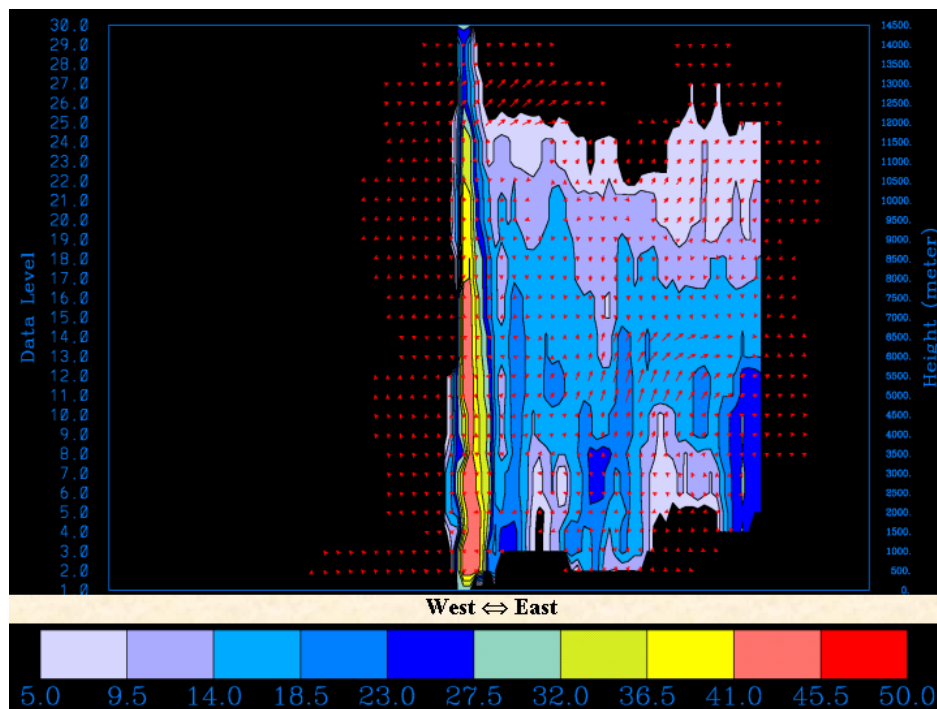


Figure 4. Vertical cross-section of observed radar reflectivity (dBZ) and retrieved wind increments (wind analysis minus first guess winds) at 00 UTC 10 May 2003.

IMPACT/APPLICATIONS

The addition of an urban canopy parameterization, in conjunction with a radar data assimilation system appropriate for urban scales, will have a tremendous impact on the predictive capability of COAMPS. The improved thermodynamic and wind structures predicted by COAMPS, in conjunction with passive tracer or dust transport, or effectively coupled to tactical decision aids, can provide a significant tool to the warfighter at high horizontal resolutions.

RELATED PROJECTS

6.2 Surface (NRL-Base)

PUBLICATIONS

Holt, T., J. J. Shi, and M. Leach, 2003: High-resolution numerical modeling of the urban environment using the Navy's COAMPSTM. Battlespace Atmospheric and Cloud Impacts on Military Operations (BACIMO) 2003 Conference, 9-11 September 2003, Monterey, CA.